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Computationally Efficient Algorithm for Reducing PAPR in OFDM using Null Subcarriers

Swapnil R. Khandare[1], Shripad P. Mohani[2], and Pravin D. Dhanorkar[2]
[1]College of Engineering, Pune, India
Email: khandaresr11.extcmtech@coep.ac.in
[2]College of Engineering, Pune, India
Email: {spmohani.extc, dhanorkarpd11.extcmtech}@coep.ac.in

Abstract- **A new algorithm is proposed which is used with existing null-data subcarrier switching method of Peak to Average Power Ratio (PAPR) reduction in OFDM to lower the computational complexity. This proposed algorithm is very simple and achieves significant reduction in computational overhead without sacrificing PAPR reduction capability of null-data subcarrier switching method. The proposed algorithm is compatible with the current commercial systems and it can be used with other existing algorithms to reduce the computational overhead further. The proposed algorithm is very useful in delay sensitive services. The effectiveness of the proposed algorithm is demonstrated by presenting simulation results of PAPR and computational time requirement.**

Index Terms—**Bit error rate (BER), Multicarrier, Orthogonal frequency division multiplexing (OFDM), Peak to average power ratio (PAPR).**

I. Introduction

Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation scheme. It is a special case of multicarrier transmission technology, where a single data stream is transmitted over a number of lower rate subcarriers instead of single carrier system [8]. The main reason to use OFDM is its robustness against the selective fading or narrowband interference, high spectral efficiency and easy implementation. Hence, due to favorable features, it is widely used in modern broadband communication systems. Despite all favorable features in OFDM system for implementation in communication systems, it encounters a noticeable problem of high peak to average power ratio (PAPR) [7]. High PAPR becomes huge obstruction to harvest all the features of OFDM system for the implementation of high speed broadband communication systems.

The OFDM signal, which superposes many individual sinusoidal subcarriers, would have high amplitude when these sinusoids are in phase at the inverse fast Fourier transform (IFFT) input, and are thus added constructively to generate large amplitude corresponding to a high PAPR at the IFFT output. When the peak amplitudes of OFDM signals with high PAPR reach or exceed the saturation region of power amplifier at the transmitter and a low noise amplifier at the receiver, the OFDM signals will suffer from nonlinear distortion, spectrum spreading, in band distortion and inter modulation distortion across the OFDM subcarriers [4]. All these demote the bit error rate (BER) at the receiver. One simple solution is to use expensive power amplifiers with large saturation region. However, as high peak amplitudes occur irregularly, these power amplifiers would be inefficient. Besides, high peak are also constrained by design factors such as cost and battery power of electronics. Large PAPR also demands the digital to analog converter (DAC) with enough dynamic range to accommodate the large peak of the OFDM signals. Although, a high precision DAC supports high PAPR with a reasonable amount of quantization noise, but it might be very expensive for a given sampling rate of the system. Whereas, a low precision DAC would be cheaper, but its quantization noise will be significant, and as a result it reduces the signal to noise ratio (SNR) when the dynamic range of DAC is increased to support high PAPR [6]. Furthermore, OFDM signals show Gaussian distribution for large number of subcarriers, which means the peak signals rarely occur and uniform quantization by analog to digital converter (ADC) is not desirable. If clipped, it will introduce in band distortion and out of band radiations (adjacent channel interference) into the communication systems [2], [5].

Therefore, the best solution is to reduce the PAPR before OFDM signals are transmitted into nonlinear high power amplifier (HPA) and DAC. Reference [1] shows the method that reduces the PAPR of multi-carrier transmission, by exploiting null subcarriers, already mandated in most OFDM wireless standards. But, this method requires high computational overhead. In this paper, method is proposed that achieves significant reduction in computational requirement without sacrificing PAPR reduction capability.
The rest of this paper is organized as follows. In Section II, PAPR reduction technique by switching null and data subcarriers is described and analyzed. In Section III, new computationally efficient PAPR reduction method is proposed. In Sections IV, performance of proposed method is reported. Section V contains the conclusions.

II. PAPR Reduction by Switching Null And Data Sub-carriers

Based on the IEEE 802.11a standard specifications, [1] proposed PAPR reduction method by switching null and data subcarriers. The main idea here is to switch one or more null-carriers with to-be-identified data- subcarrier(s). This changes the input to the IFFT operator, and thus the IFFT operator's output and it's PAPR.

Consider an OFDM transmission with L subcarriers at

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the frequencies { f_ℓ, ℓ = 1. . . L} listed ascending and indexed by S = { ℓ = 1. . . L}. Of these, N are null subcarriers, with indices drawn from the ascending set N = {g_n, n = 1. . . N} $\subset$ S, respectively occupying the ascending frequencies {fg_n, n = 1. . . N}. The remaining L - N subcarriers serve as data-subcarriers, with indices from the ascending set D = {h_d, d = 1. . . L - N} $\subset$ S, respectively occupying the ascending frequencies {fh_d, d =1. . . L - N}. Obviously, N $\cup$ D = S, and $fg_n \neq fh_d$, $\forall$ n, d. Assigned to the data-subcarriers at {fh_d, $\leq$ d $\leq$ L -N} are, respectively, the M-ary data symbols {X_d, d = 1. . . L -N}, taken from any phase-modulated and/or amplitude-modulated constellation. Without modifying L or N specified in a given OFDM standard, the method switches P number of null subcarriers (i.e. {g_p, p= 1, . . . , P} $\subset$ N ={g_n, n = 1, . . . , N}) with P number of data-subcarriers (i.e. P members of {h_p, p = 1, . . . , P} $\subset$ D = {h_d, d = 1, . . . , L " N}), such that if $fh_p < fh_{p+1}$, then $fg_p < fg_{p+1}$.

The above constraint (i.e. if $fh_p < fh_{p+1}$ then $fg_p < fg_{p+1}$) allows no channel side information to be transmitted, because:

- The receiver has a priori knowledge of D;
- The received data allow the identification of {h_p, p = 1, . . . , P} on account of their low power-levels; and
- The permutation of the P switched data-subcarriers remains unchanged after the switching. Hence, the receivers can 'un-switch' correctly, even with no channel side information.

The task is to identify the {h_p, p =1. . . P} (from {h_d, d = 1. . . L - N}) that minimizes the PAPR z, of the discrete-time OFDM signal. With L, N, P specified, there exist altogether

$$\binom{L-N}{P} = \frac{(L-N)!}{P!(L-N-P)!} \tag{1}$$

number of different 'switching' possibilities, for each of which the transmitter is to evaluate the corresponding PAPR z. To be chosen will be the one 'switching' possibility that offers the least PAPR z. As per 802.11a specification, Number of data subcarriers (L-N) =48, if P=2 is considered then 1128 numbers of iterative searching are required. This means 1128 times IFFT needs to be performed for every single OFDM symbol. The number becomes 194580 if P = 4 is considered. This implies that the computational time and associated energy cost can be a hindrance for delay sensitive services or power constrained hand-held devices. Thus new algorithm is proposed which reduces the computational burden of null-data subcarrier switching.

III. Proposed Method

To overcome the limitation of [1], proposed method segregates the data subcarriers into subcarriers bands and then finds the band with maximum PAPR. Once the band with maximum PAPR value is found then perform null-data subcarrier switching in that band. By doing this, searching can be done with less computational burden and also retains the advantage of no side information. The flowchart of this proposed method is shown in Fig. 1. The method is explained in detail here. First, total numbers of data subcarriers are divided into certain number of bands. As per 802.11a standard, there are 48 data subcarriers. If we divide it into 4 sub-bands then each band will have only 12 subcarriers. Then oversampling is performed by certain factor to match with the IFFT size. Now, IFFT operation is performed for each sub-band and PAPR value of each sub-band is found. The main idea here is to find the sub-band having maximum PAPR value. Once this sub-band is found, then switching of null subcarriers with data subcarriers is performed only for that sub-band.

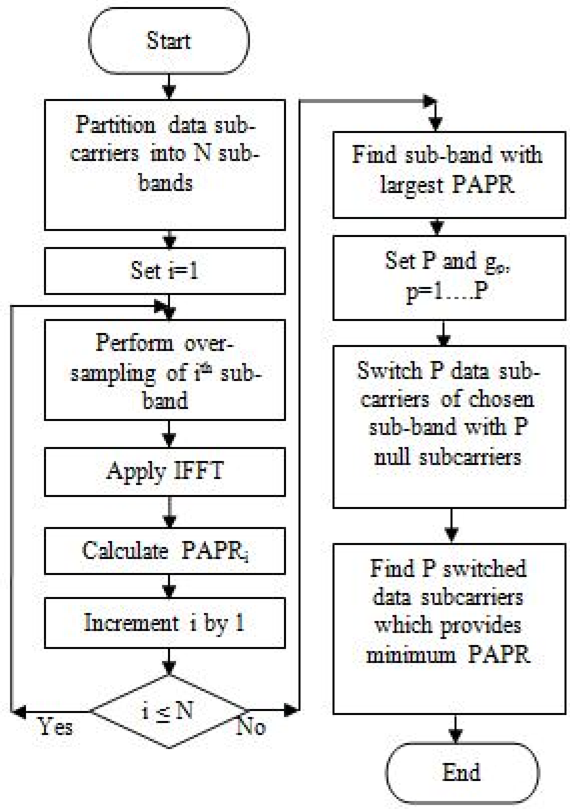

Fig.1 Flowchart of proposed method

This proposed method reduces the computational burden significantly, as for example, with P=2, the proposed method requires 66 number of searching operations as compared to 1128 of the null-data subcarrier switching method. If we consider P=4, then corresponding numbers are 495 and 194580, respectively. Our proposed method can achieve even higher computational complexity reduction for higher values of P. However, for higher values of P, number of switching possibilities will reduce which will results into lower PAPR reduction capability. Simulation results show that with this large amount of computational requirement reduction, proposed method has almost the same level of PAPR reduction capability when compared with the null-data subcarrier switching method.

IV. Simulation Results

In this work, the simulation is carried out using MATLAB 7.11 simulation tool. To verify the proposed PAPR reduction technique with low computational overhead, the IEEE 802.11a

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standard is used herein, even though proposed method can be implemented in any multicarrier system with null-subcarriers. Parameters related to simulation are given in Table I. Any modulation scheme can be used as per requirement but 16-QAM is used here because it attains more PAPR reduction as compared to QPSK. Use of 64-QAM has the effect of higher BER than any other modulation technique [9]. For comparative performance analysis, a sample case is investigated for P=2. To minimize possible degradation of the guard-bands, the innermost null sub-carriers at low frequency or high frequency edge are used [1]. Other parameters are according to IEEE 802.11a standard. The 48 data subcarriers are divided into 4 sub-blocks with oversampling. Only that sub-block having largest PAPR value undergoes the switching method.

TABLE I. SIMULATION PARAMETERS

Modulation Scheme	16-QAM
IFFT size	64
Number of data subcarriers	48
Number of switched null subcarriers (P)	2
Total number of OFDM symbols	100
Channel model	AWGN

Fig. 2 shows the comparative complementary cumulative distribution function (CCDF) of PAPR for OFDM without any PAPR reduction, null-data subcarrier switching method and proposed method. From fig. 2, it can be seen that the maximum value of PAPR for OFDM system without any PAPR reduction technique is 10.8 dB but PAPR value of null-data subcarrier switching method and proposed method cannot exceed 9 dB and 9.1 dB respectively. Thus, the proposed method has almost the same PAPR reduction characteristics as the null-data subcarrier switching method but with low computational overhead. It is important to recall that the number of searching operations for the proposed method and null-data subcarrier switching method are 66 and 1128, respectively, which implies that compared to the null-data subcarrier switching method, proposed method shows almost the same level of PAPR reduction with 94.15% computational burden reduction.

If this proposed method is combined with technique in [3], then PAPR reduction capability is reduced but for P=2, maximum number of searching operations required will be 23 only; that means nearly 98% computational burden reduction.

Fig. 3 shows the CCDF of PAPR for OFDM without any PAPR reduction, the null-data subcarrier switching method and proposed method combined with technique in [3]. From fig. 3, it can be seen that the maximum value of PAPR for OFDM system without any PAPR reduction technique is 9.2 dB but PAPR value of null-data subcarrier switching method and proposed method cannot exceed 7.8 dB and 8.5 dB respectively. Thus, the proposed method shows PAPR reduction characteristics with nearly 98% computational burden reduction.

Table II shows the trade-off between PAPR and computational time reduction for null-data subcarrier switching, proposed method and proposed method combined with technique in [3].

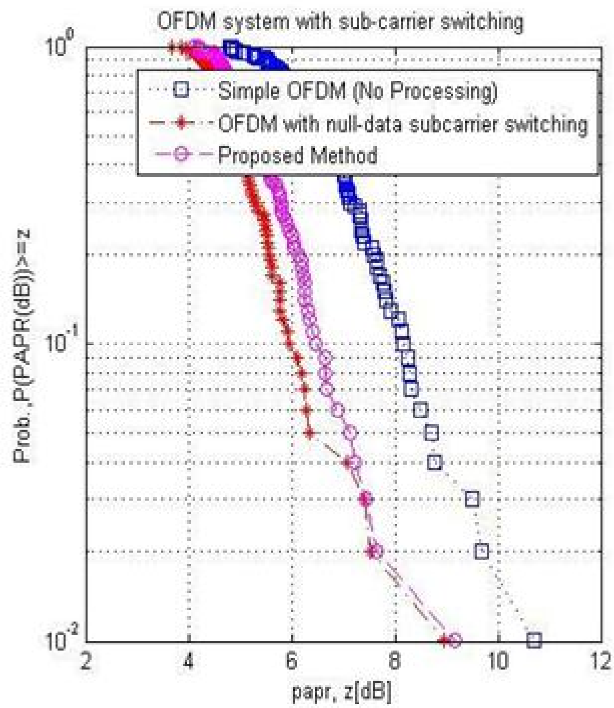

Fig. 2 Comparative plot for CCDF of PAPR

TABLE II. TRADE-OFF BETWEEN PAPR AND COMPUTATIONAL TIME

Method Used	PAPR Reduction (%)	Reduction in computational time (%)
Null-data subcarrier switching	26	--
Proposed	23.5	92
Proposed combined with technique in [3]	12	98

Results in Table II are obtained using MATLAB 7.11 simulation tool.

Fig. 4 shows the Comparative plot of BER Vs E_b/N_0. Number of switching possibilities are more in the null-data subcarrier switching method as compared to the proposed method which leads to more error probability in the null-data subcarrier switching method as compared to the proposed method. From fig.4, it can be seen that proposed method shows BER performance which is better than that of null-data subcarrier switching method.

V. CONCLUSION

A new approach of a null and data subcarrier switching scheme for PAPR reduction in OFDM is proposed in this paper. Using simulation results, the PAPR reduction capability and the BER performance of proposed method is also shown. Proposed method achieves nearly same PAPR reduction with very low computational overhead compared to the

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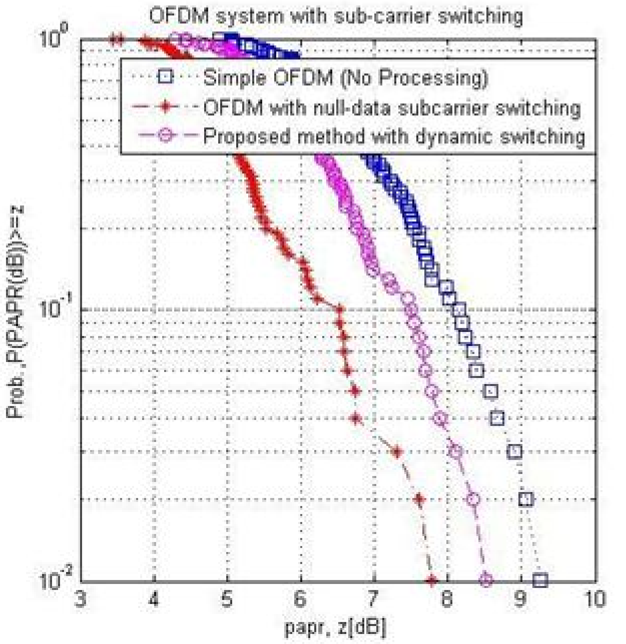

Fig. 3 CCDF plot for proposed method combined with technique in [3]

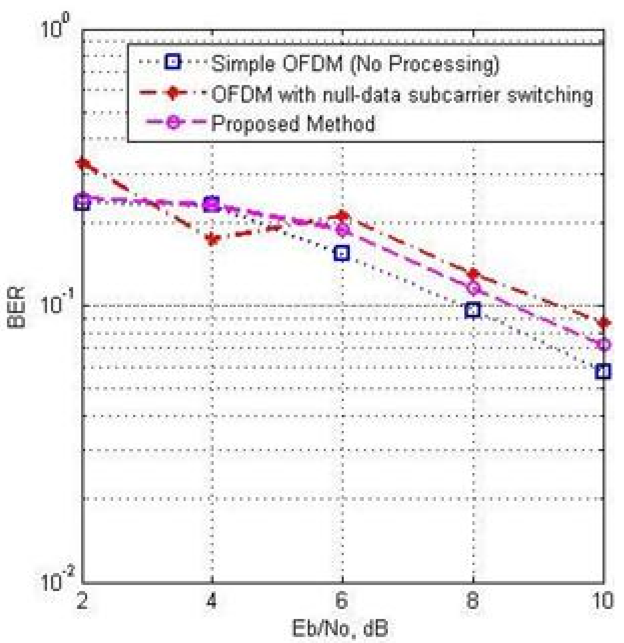

Fig. 4 Comparative plot of BER Vs E_b/N_0

null-data subcarrier switching method. Also, it retains the advantage of no side information. To reduce computational overhead to large extent, proposed method can be used in combination with existing low computational overhead methods.

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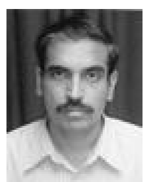
Mr. Swapnil R. Khandare is pursuing Master of Technology in Wired & Wireless Communication from College of Engineering, Pune, India. He completed his Bachelor of Technology in Electronics and Telecommunication in 2010. His current research interests include the areas of wireless communications, especially for OFDM systems with emphasis on research of PAPR reduction techniques.



Mr. Shripad P. Mohani is Associate Professor in Electronics and Telecommunication Engineering Department, College of Engineering, Pune, India. He completed his Bachelor of Engineering in Electronics and Telecommunication in 1991 and subsequently completed his Masters of Engineering in Electronics and Telecommunication in 1998. His areas of interest and work are Digital Communication, OFDM and Signal Processing.

Mr. Pravin D. Dhanorkar is pursuing Master of Technology in Wired & Wireless Communication from College of Engineering, Pune, India. He completed his Bachelor of Technology in Electronics and Telecommunication from SGGSIE&T Nanded in 2011. His M.Tech Dissertation is in the area of OFDM technology. His areas of interest are Digital Communication and OFDM.

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